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Manfredi

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(54) **CMP SLURRY ATOMIZATION SLURRY DISPENSE SYSTEM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(51) **Int. Cl.**[7] **B24B 57/00**
(52) **U.S. Cl.** **156/345**; 451/446; 261/90
(58) **Field of Search** 156/345; 216/88, 216/89, 90; 451/282, 283, 284, 285, 286, 288, 289, 66; 51/308; 438/690, 691, 692, 693, 694

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,997,392 * 12/1999 Chamberlin et al. 451/446
6,146,241 * 11/2000 Lee et al. 451/5

* cited by examiner

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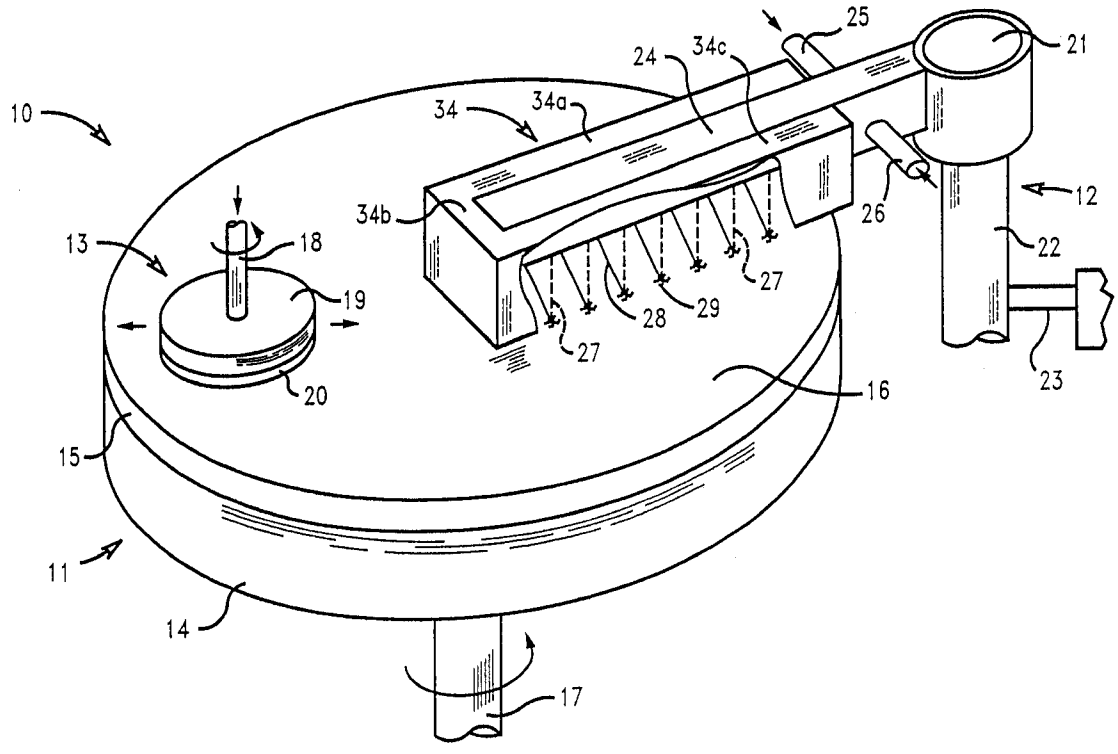
(57) **ABSTRACT**

An apparatus for polishing a semiconductor wafer is provided comprising a wafer carrier to provide a force against a wafer and a rotating polishing pad during the polishing operation and a polishing slurry dispenser device disposed to dispense the slurry toward the pad preferably as a stream or more preferably drops toward the pad surface and a curtain of air to intersect the slurry at or near the polishing pad surface. The wafer is polished using less slurry than a conventional polishing apparatus while still maintaining the polishing rates and polishing uniformity of the prior art polishing apparatus. A preferred dispenser is an elongated housing having a slurry tube and air tube therein each tube having a plurality of spaced apart slurry openings and air openings along its longitudinal axis which tube is preferably positioned radially over at least one-half the diameter of the polishing pad. A polishing slurry is directed from the slurry tube toward the surface of the pad, preferably in the form of drops, and the air from the air tube forms an air curtain, with the air curtain intersecting the slurry drops preferably at or slightly above the pad surface to atomize the slurry.

11 Claims, 2 Drawing Sheets



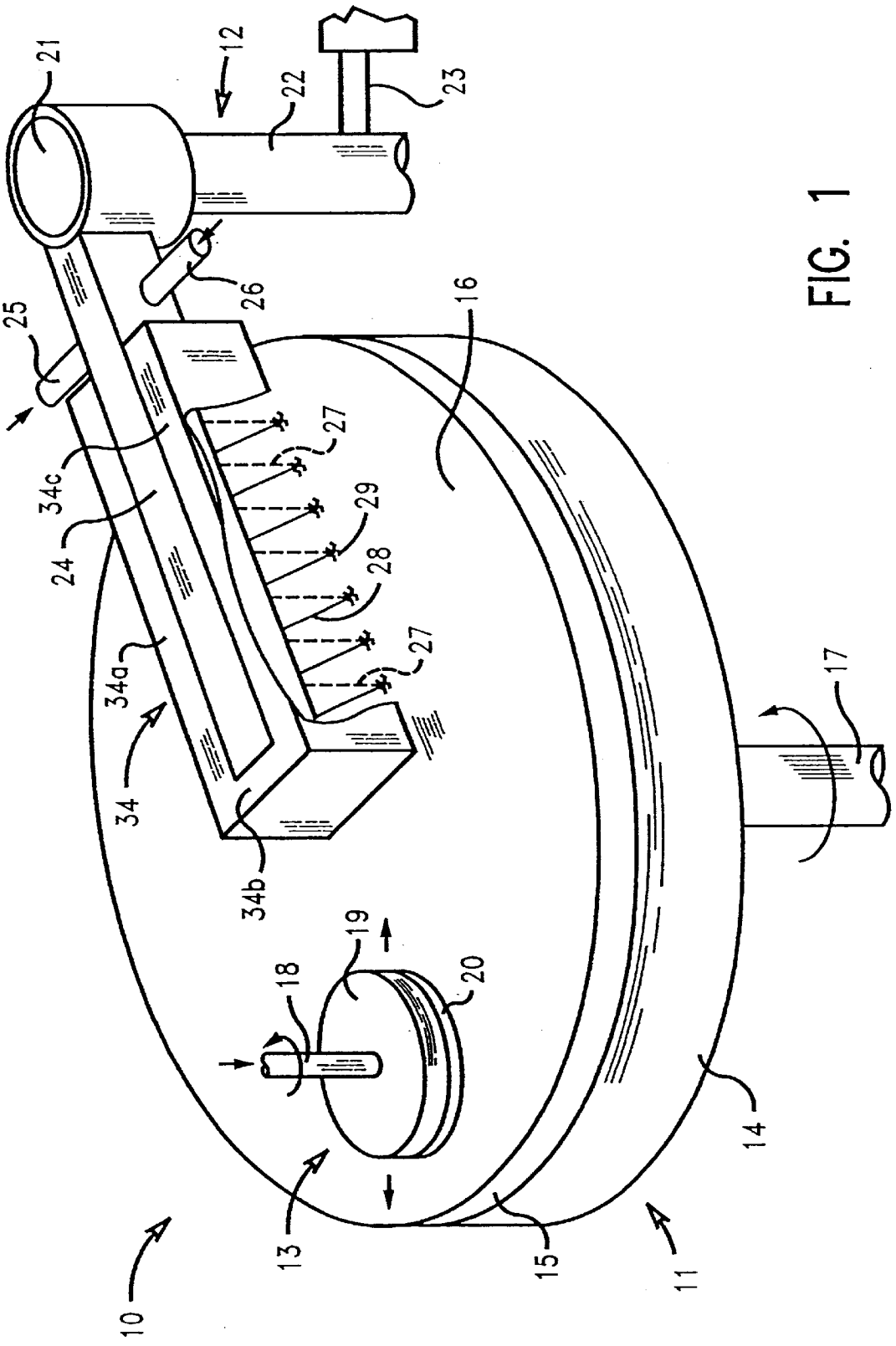

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FIG. 1

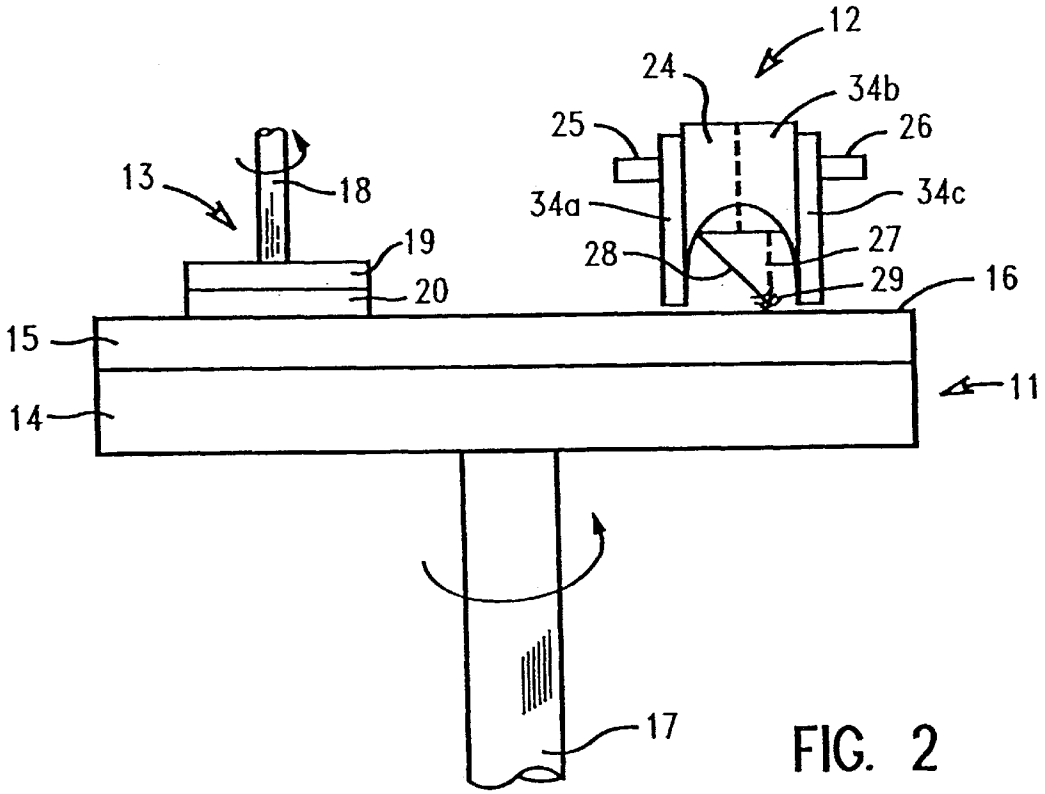
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FIG. 2

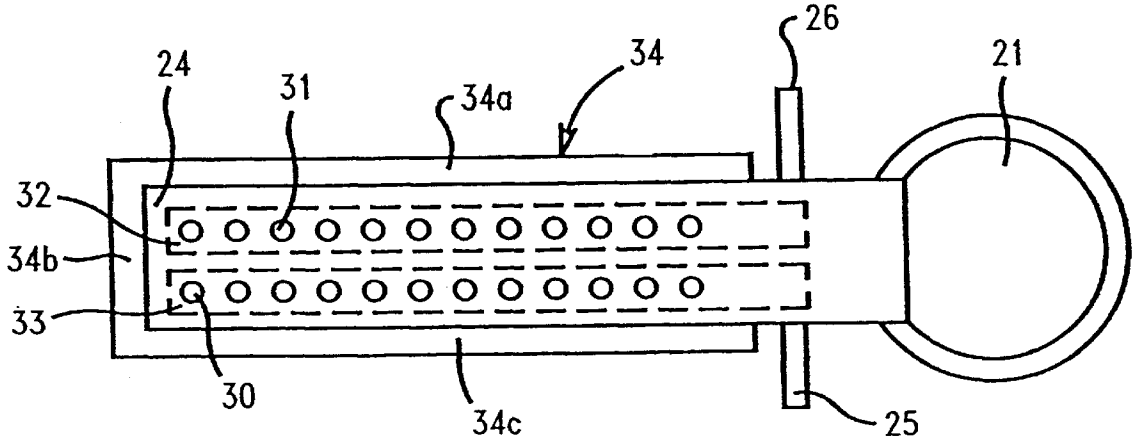
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FIG. 3

CM P SLURRY ATOMIZATION SLURRY DISPENSE SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to processing of semiconductor wafers and other electronic substrates such as slices of semiconductor silicon and other articles requiring a planar surface, and, more particularly, to an improved method and apparatus for polishing the wafers using the chemical-mechanical planarization (CMP) process and achieving high polishing rates and wafer planarity and uniformity while using smaller amounts of the chemical slurry than conventionally used in the CMP process.

2. Problem to be Solved

In the manufacture of integrated circuits wafer surface planarity is of extreme importance. Photolithographic processes are typically pushed close to the limit of resolution and it is essential that the wafer surface be highly planar so that the electromagnetic or other radiation used to create the integrated circuit may be accurately focused in a single level thus resulting in precise imaging over the entire surface of the wafer. Wavy, curved or wedge-shaped semiconductor disks result in lack of definition when, for example, a photosensitive resist is applied to the surface of a "non-planar" disk and exposed.

In order to achieve the degree of planarity required to produce ultra high density integrated circuits, chemical-mechanical planarization processes are now typically employed in the industry. In general, the chemical-mechanical planarization (CMP) process involves pressing a rotating semiconductor wafer or other such electronic component or other substrate against a moving polishing surface that is wetted with a chemically reactive, abrasive slurry. The slurries are usually either basic or acidic and generally contain alumina or silica particles. The polishing surface is typically a planar pad made of a relatively soft, porous (open pored) material such as blown polyurethane. The pad is usually mounted on a planar rotating turntable platen but may also be a rectilinear moving endless belt as is known in the art.

In general, for a rotating turntable the wafer is secured to a carrier plate (or wafer carrier) by vacuum or by a mounting medium such as an adhesive, with the wafer having a force load applied thereto through the carrier by a pressure plate so as to press the wafer into frictional contact with a polishing pad mounted on a rotating turntable. The carrier and pressure plate also rotate as the result of either the driving friction from the turntable or rotation drive means directly attached to the pressure plate. A typical way of securing and releasing the wafer is by the use of a vacuum head that includes a rigid perforated plate against which the wafer is drawn by applying a vacuum to a plenum lying above the perforated plate.

All chemical-mechanical polishing (CMP) processes are dependent on the ability of a polishing template, or pad, to transport the polishing medium, or slurry, to the substrate surface efficiently. This transport of slurry is inhibited by the gradual accumulation of polishing by-products on the template or pad surface. These by-products tend to fill the natural surface porosity of the pad as the polishing process continues over time, and this causes the polishing rate to decrease and the non-uniformity of the polishing process to increase.

Polish by-products may be partly removed by "flooding" the pad surface with additional slurry, although this is an expensive response to the basic problem, and it is not completely effective. For these reasons, the polishing process is expensive to control, especially in high-volume production applications. Due to a lack of polish-rate stability, it is difficult to predict the duration of a polishing process, and the polish times tend to increase on successively polished substrates unless the polishing surface is treated by specific means. These problems decrease product throughput, which is a major cost-driver in CMP.

Surface transport issues also affect the uniformity of the polishing across the substrate surface. Further, the buildup of polish by-products on the pad surface may also increase the incidence of physical defects on the wafer surface. Both of these latter problems (uniformity and defects) also increase production costs, because they may decrease product yields, another primary driver of process costs.

A current method of chemical slurry application involves dripping slurry onto the polishing pad through a tube so as to pool the slurry in the center of the pad. This method is generally inefficient to coat the pad and excess slurry is typically applied to maintain a fluid layer between the pad and the wafer. A fluid layer is considered necessary to achieve an acceptable polishing rate and polishing uniformity.

U.S. Pat No. 4,910,155 describes the basic CMP process and utilizes a retaining wall around the polishing pad and polishing table to retain a pool of slurry on the pad. U.S. Pat No. 5,403,228 discloses a technique for mounting multiple polishing pads to a platen in a CMP process. A seal of material impervious to the chemical action of the polishing slurry is disposed about the perimeter of the interface between the pads and when the pads are assembled the bead squashes and forms a seal and causes the periphery of the upper pad to curve upward creating a bowl-like reservoir for increasing the residence time of slurry on the face of the pad prior to overflowing the pad. U.S. Pat No. 3,342,652 shows a process for chemically polishing a semiconductor substrate and a slurry solution is applied to the surface of the pad in bursts as a stream forming a liquid layer between the cloth and the wafers to be polished. The solution is applied from a dispensing bottle and is applied tangentially to the wafer-plate assembly so as to provide maximum washing of the polishing cloth in order to remove waste etching products. U.S. Pat. No. 4,549,374 shows the use of a specially formulated abrasive slurry for polishing semiconductor wafers comprising montmorillonite clay in deionized water.

All the above patents are hereby incorporated by reference.

Bearing in mind the problems and deficiencies of the prior art, it is therefore an object of the present invention to provide an apparatus, e.g., a CMP apparatus, for polishing semiconductor wafers and other workpieces using smaller amounts of the chemical or other slurry used to polish the workpiece while still maintaining the polishing rate and uniformity of the polished surface.

It is another object of the present invention to provide an improved method for polishing workpieces, e.g., semiconductor wafers, using such a polishing apparatus as the CMP system and using the improved CMP apparatus of the invention.

It is an additional object of the invention to provide a spray atomization device for use in a polishing apparatus for polishing electronic substrates such as wafers, e.g., using a CMP apparatus, and for use in polishing methods such as CMP methods to enhance the efficiencies and operation of the CMP apparatus and method.

It is a further object of the invention to provide planar workpieces, including semiconductor wafers, made using the improved method and apparatus of the invention.

Other objects and advantages of the present invention will be readily apparent from the following description.

SUMMARY OF THE INVENTION

The above and other objects, which will be apparent to those skilled in the art, are achieved in the present invention which is directed in a first aspect to a method for polishing workpieces such as semiconductor wafers and other electronic component substrates using a polishing pad which comprises forming an atomized polishing slurry which is directed onto the surface of the pad. The atomized polishing slurry is preferably formed by directing the slurry at the surface of the pad preferably by a plurality of slurry streams and most preferably drops of the slurry preferably substantially transverse to the plane of the polishing pad and preferably across about one-half the pad diameter and intersecting the slurry streams or drops with a curtain of air which intersects the slurry preferably at or slightly above the pad surface and atomizes the slurry and forms an atomized slurry which effectively wets the pad surface.

In a preferred embodiment, the method comprises securing the wafer to the lower surface of wafer carrier means and applying a force to the upper surface of the wafer carrier to contact the wafer with a polishing pad and providing an atomized polishing slurry distributed on the pad surface. The atomized polishing slurry is applied to the polishing pad and is formed by an intersecting streams of air and slurry. The atomized slurry is dispersed uniformly over at least a part of the pad surface. Using the method and apparatus of the invention it has been found that the polishing rate and wafer uniformity can be substantially maintained using less polishing slurry than conventional prior art slurry application techniques.

It is preferred that a pump be employed for forming the slurry stream or preferably drops of slurry and the air be supplied under pressure of about 20 to 80 psi to provide an air curtain of about 20 to 60 psi so that the atomized slurry is applied uniformly over at least part of the polishing pad surface. Preferably a slurry and air dispenser device having an air inlet and a slurry inlet is disposed over the pad surface and comprises an elongated rectangular or tubular device holding a tube or conduit for each of the air and slurry inlets and each tube or conduit having a plurality of parallel spaced apart first slurry openings and second air openings therein along the longitudinal axis of the conduit. The length of the device (and conduit) is preferably about half the diameter of the polishing pad and is disposed radially over one-half of the polishing pad surface so that about one-half of the pad surface is sprayed with the atomized slurry at one time. Since the pad is rotating, the spray will contact the whole surface continually during the polishing process. The slurry is fed into the dispenser device and the slurry directed at the wafer preferably as a stream and most preferably as drops toward the polishing pad through the openings therein during the polishing operation. The pressure on the slurry feed may vary widely and is typically about 1–10 psi, e.g., 3 psi. The slurry stream or drops are preferably transverse to the polishing pad surface with the drops falling to the pad surface without any significant pressure. The air curtain is angled and intersects the slurry stream or drops and atomizes the slurry. The wafer is typically moved over the other half of the polishing pad.

The preferred method of the invention for polishing workpieces such as semiconductor wafers and other electronic substrates using a polishing pad comprises the steps of:

providing a movable carrier for holding a polishing pad such as a rotatable turntable assembly or a linearly moving endless belt;

providing a polishing pad supported on said movable carrier;

providing a rotatable carrier located above said assembly and adapted to hold a workpiece during polishing, with said workpiece secured on the lower surface of the rotatable carrier and positioned between said rotatable carrier and said polishing pad so that when a force is applied to the upper surface of the rotatable carrier the workpiece contacts the polishing pad and the rotatable carrier provides a force across the workpiece surface such that the polishing process imparts a flat polished wafer surface;

providing a dispensing means preferably elongated and preferably disposed radially over at least part of the pad surface the dispenser having a tube or conduit for each of a slurry and air inlet feed stream and having a plurality of spaced apart first and second parallel openings therein along the longitudinal axis of the dispensing means, the dispensing means having an inlet for a chemical slurry and an inlet for compressed air or other gas;

feeding slurry to the dispensing means and forcing the slurry through the first openings toward the pad preferably forming a plurality of slurry streams or preferably drops which are directed downwardly at the polishing pad surface;

providing compressed air to the dispenser forcing air through the second openings downwardly and preferably angularly at the polishing pad surface forming an air curtain which curtain intersects the slurry streams or drops and atomizes the slurry streams or drops preferably at or near the pad surface; and

moving the rotatable carrier on the pad surface and polishing the wafer held in the carrier.

In an additional aspect of the invention an apparatus is provided for polishing a surface of a workpiece such as a semiconductor wafer comprising:

a movable carrier for holding a polishing pad such as a rotatable turntable assembly or a linearly moving endless belt;

a polishing pad supported on said movable carrier;

a rotatable carrier, located above said assembly and adapted to hold a workpiece during polishing, with said workpiece secured on the lower surface of the rotatable carrier and positioned between said rotatable carrier and said polishing pad so that when a force is applied to the upper surface of the rotatable carrier the workpiece contacts the polishing pad and the rotatable carrier provides a force across the workpiece surface such that the polishing process imparts a flat polished wafer surface;

dispensing means preferably disposed preferably radially over at least part of the surface of the polishing pad comprising an elongated tube or conduit for each of a slurry and air feed inlet streams and having a plurality of spaced apart first and second parallel openings therein along the longitudinal axis of the dispensing means;

slurry pressure means to feed a polishing slurry into the dispensing means forcing the slurry through the first openings toward the pad preferably forming a plurality of slurry streams or drops which are directed downwardly at the polishing pad surface;

air pressure means to feed air into the dispenser means forcing the air through the second openings downwardly and preferably angularly at the polishing pad surface forming an air curtain which curtain intersects the slurry streams or drops and atomizes the slurry streams preferably at or near the pad surface.

In another aspect of the invention wafers and other workpiece articles are provided which have been polished using the method and apparatus of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the invention believed to be novel and the elements characteristic of the invention are set forth with particularity in the appended claims. The figures are for illustration purposes only and are not drawn to scale. The invention itself, however, both as to organization and method of operation, may best be understood by reference to the detailed description which follows taken in conjunction with the accompanying drawings in which:

FIG. **1** is a perspective schematic cut away illustration of a typical CMP apparatus for polishing a semiconductor wafer utilizing the chemical slurry dispensing means of the invention.

FIG. **2** is a side elevational cut away view of the CMP apparatus of FIG. **1** facing the free end of the chemical slurry dispensing device of the invention.

FIG. **3** is a bottom plan cut away view of the chemical slurry dispensing device of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT(s)

In describing the preferred embodiment of the present invention, reference will be made herein to FIGS. **1–3** of the drawings in which like numerals refer to like features of the invention. Features of the invention are not necessarily shown to scale in the drawings.

Referring to the drawings, FIG. **1** shows a typical CMP apparatus for polishing a semiconductor wafer which apparatus has been modified using a chemical slurry dispensing means of the invention. The polishing apparatus shown generally as **10** includes a polishing wheel assembly shown generally as **11**. The polishing wheel assembly includes a polishing table **14** to which is attached a polishing pad **15** having an upper surface **16**. A conventional pad is a Rodel IC1000 polyurethane pad. The polishing table **14** is rotated by shaft **17** in the direction indicated by the arrow by any suitable motor or driving means (not shown). The polishing pad is typically polyurethane foam having open pores and is about 22 inch in diameter and 0.050 inch thick.

A wafer carrying assembly shown generally as **13** includes a wafer carrier **19** shown holding wafer **20**. Pressure is supplied to the wafer carrier **13** for applying pressure to the wafer carrier and wafer. In the embodiment shown, a hollow spindle **18** is coupled to the wafer carrier **19** and is driven by a suitable motor or driving means (not shown) for moving the wafer carrier assembly **13** in the directions shown by the arrows. Pressure can be applied to the spindle **18** by a weight load as shown by the downward arrow and/or a pressurized fluid such as compressed air can be used to exert pressure on the wafer carrier **19**. The force is essentially uniform over the surface of the wafer carrier and wafer.

The wafer carrier assembly in a preferred embodiment moves over about one-half of the pad surface **13**. The chemical slurry dispenser device shown generally as **12** is shown as stationary and fixedly connected to support arm **23**, column **22** and dispenser device bracket **21**. The dispenser distributes a chemical slurry in the preferred drop form and an air curtain over the other half of the pad surface **16**. The bottom of the dispenser **24** is typically positioned about 0.5–3 inches above the surface of the pad but this may vary. It is also contemplated that the dispenser **24** may be disposed over the whole polishing pad and the wafer carrier **13** be moved over the whole polishing pad. The configuration shown in FIG. **1**, however, has proven effective and, as can be seen, the whole upper surface **16** of the polishing pad **15** is contacted with the atomized slurry because of the rotating motion of the polishing pad and, consequently, the wafer **20** is continually exposed to a pad **15** having slurry thereon.

During polishing, an atomized chemical slurry is applied by dispensing means **24** to the surface **16** of the pad **15** and is injected or forced into the open pores of the polishing pad and also forms a layer of slurry on the pad surface which flows between the wafer **20** carried by the wafer carrier assembly **13** and the polishing pad **15** of polishing wheel assembly **11**. Any suitable slurry may be used. Silica based slurries such as Cabot SC **112** are preferred.

The dispenser means **24** has an inlet **25** for feeding compressed air to the dispenser which is forced out of spaced apart openings **30** in tube **33** as shown in FIG. **3** as an angled curtain of air **28**. For clarity, the air curtain is shown as a plurality of streams **28** but will be appreciated that the individual streams **28** fan out and form a curtain of air which intersects the slurry **27** at **29**. The openings typically contain nozzles for providing a precise air curtain or slurry flow. The slurry is fed to the dispenser **24** through inlet **26**. The slurry is forced under pressure from the dispenser means **24** in the form of a stream or more preferably drops or droplets **27** from spaced apart openings **31** in tube **32** as shown in FIG. **3**. The chemical slurry drops **27** and the air curtain **28** meet preferably at or near the pad surface and form an atomized chemical spray **29** which impinges on the surface **16** of pad **15**. The drops **27** are essentially at zero pressure outside the dispenser and fall by gravity toward the pad surface. The slurry not only coats the upper surface **16** of pad **15** but is also forced into the pores of the pad. Using such an atomizing dispenser the polishing action of the apparatus and method of the invention has been found to be at least as comparable as for prior art devices but the improved apparatus and method uses less chemical slurry than a conventional CMP apparatus. The dispenser **24** is secured to dispenser bracket **21** which is fixedly secured through column **22** and arm **23** as described above. A suitable dispenser because of its demonstrated effectiveness is about 11 inches long and openings in the dispenser are preferably spaced uniformly over the dispenser surface with the air openings **30** and slurry openings **31** being parallel along the longitudinal axis of the dispenser. Any number of openings may be used for each conduit and typically a total of about 10–20 or more openings are provided for each air and slurry conduit.

A curtain **34** is employed around the periphery of the dispenser **24** to contain the atomized slurry and prevent loss of slurry and/or misting in the work area. The curtain **34** has sidewalls **34***a* and **34***c* and connected end wall **34***b*. The curtain extends to slightly above the pad surface.

FIG. **2** shows a side view of FIG. **1** and angled air curtain **28** is seen intersecting falling slurry drops **27** to form an atomized slurry **29** near the surface **16** of pad **15**. The slurry drops **27** may be angled and the air curtain substantially transverse to the pad or both air and slurry drops may be

angled. Curtain **34** is shown containing atomized slurry **29** within the area bounded by dispenser **24**.

As it is well known in the art, multiple wafers and/or multiple wafer carriers can be simultaneously processed on a single polishing turntable during a polishing operation.

The dispenser is preferably a longitudinal elongated housing **24** having a tube or conduit therein for each of the slurry (tube **32**) and air (tube **33**) and each having a plurality of openings **31** and **30** in each tube as shown in FIG. **3**. Preferably, the openings have nozzles secured therein which provide a desired air or slurry flow pattern. Any suitable nozzle means can be employed. It is preferred that the openings and/or nozzles **31** form the slurry into the form of drops or droplets. The air openings **30** preferably form a curtain of air which is angled to intersect the slurry drop stream at or near the pad surface **16**. The dispenser **24** is disposed over the polishing pad surface **16**. The dispenser may also be configured and mechanically linked to the wafer carrier assembly **13** to move simultaneously together over the polishing pad while dispensing the chemical slurry and air onto the pad surface. Preferably, the slurry is dropped downward, preferably substantially transverse to the polishing pad surface and the air is supplied at an angle to the drops and intersects the drops preferably at or slightly above the pad surface **16**. The dispenser may also comprise a separate slurry supply means and air supply means which are positioned adjacent each other to provide said intersecting streams and atomization of the slurry.

It is an important aspect of the invention that when the CMP apparatus is idle (e.g., no slurry and air is being passed through the dispenser) that the dispenser be rinsed preferably using deionized water by passing the water through the air and slurry conduits. This minimizes hole opening blockage and enables continued use of the CMP apparatus with a minimum of down-time.

EXAMPLE

A conventional CMP apparatus was used to polish semiconductor wafers 22 inch in diameter and about 150 ml/min. of slurry was used. Using a similar CMP apparatus but with a slurry and air dispenser as shown in FIGS. **1–3**, about 105 ml/min. slurry in the form of drops was used and the same wafer polishing was achieved. The dispenser was about 11 inches long and the air conduit and slurry conduit contained a plurality of spaced apart openings along the longitudinal axis. The air pressure was 30 psi and the slurry pressure 3 psi. The slurry exited the openings as drops which fell toward the pad and the air exited each nozzle opening at about 0.22 ft^3/min (cfm).

While the present invention has been particularly described, in conjunction with a specific preferred embodiment, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art in light of the foregoing description. It is therefore contemplated that the appended claims will embrace any such alternatives, modifications and variations as falling within the true scope and spirit of the present invention.

Thus, having described the invention, what is claimed is:

1. An apparatus for polishing a surface of a workpiece comprising:

a movable carrier for holding a polishing pad;

a polishing pad supported on said carrier;

a rotatable carrier, located above said polishing pad and adapted to hold a workpiece during polishing, with said workpiece held on the lower surface of the rotatable carrier and positioned between said rotatable carrier and said polishing pad which when a force is applied to the upper surface of the rotatable carrier to contact the workpiece with the polishing pad the rotatable carrier provides a force across the workpiece surface such that the polishing process imparts a flat polished surface on the workpiece;

dispensing means disposed over the surface of the polishing pad comprising a tube or conduit for each of a slurry and air feed inlet streams and having a plurality of spaced apart first and second parallel openings therein along the longitudinal axis of the dispensing means;

slurry pressure means to feed a chemical polishing slurry into the dispensing means forcing the slurry through the first openings of the slurry tube toward the polishing pad surface;

air pressure means to feed air into the dispenser means forcing the air through the second openings of the air tube downwardly at the pad surface and forming an air curtain which air curtain intersects the slurry and atomizes the slurry at or near the pad surface.

2. The apparatus of claim **1** wherein the workpiece is a semiconductor wafer.

3. The apparatus of claim **2** wherein the slurry directed at the pad surface is in the form of drops.

4. The apparatus of claim **3** wherein the dispensing means comprises an elongated housing having an elongated slurry tube and air tube therein each tube having a plurality of spaced apart openings along the longitudinal axis of the dispensing means.

5. The apparatus of claim **4** wherein the openings contain nozzles therein.

6. The apparatus of claim **5** wherein the polishing pad is polyurethane.

7. The apparatus of claim **6** wherein the dispensing means forces the slurry and air over about half of the diameter of the surface of the polishing pad.

8. The apparatus of claim **7** wherein the dispensing means is disposed radially over about half the pad surface.

9. The apparatus of claim **8** wherein the pressure of the air curtain is about 20 to 60 psi.

10. As an article of manufacture, a chemical slurry dispenser for use in a chemical-mechanical polishing process comprising an elongated conduit for forcing a slurry through a plurality of openings therein so that the slurry is directed toward a polishing pad and an elongated conduit for forming an air curtain and directing the curtain of air to intersect the slurry at or near the pad surface atomizing the slurry wherein wafers or other electronic component substrates to be polished are held against a rotating polishing pad by a carrier which provides a force across the surface of the wafer and imparts a flat polished surface on the wafer.

11. The article of claim **10**, wherein the tubes or conduits for the slurry stream and the air stream are contained in an elongated housing and each have a plurality of longitudinal spaced apart openings for providing a plurality of slurry streams or drops and an intersecting air curtain formed of a plurality of air streams exiting the dispenser.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

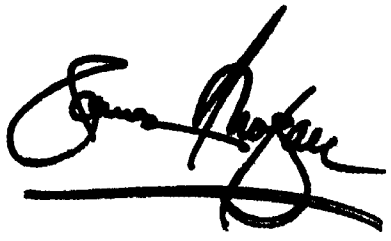
PATENT NO. : 6,284,092 B1
DATED : September 4, 2001
INVENTOR(S) : Manfredi

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 1,
Line 1, please delete "CM P" and substitute therefor -- CMP --.

Signed and Sealed this

Fifth Day of August, 2003



JAMES E. ROGAN
Director of the United States Patent and Trademark Office